WBS	Task Name	Budget	Spent
0	ARCHES	$2,500,564	$494,350
1	Integrated Ground PlaneTechnical Dev.	$1,381,843	$325,962
1.1	Passive Broadband AMC Dev.	$325,981	$283,145
1.2	Reconfigurable Bandgap AMC Dev.	$545,363	$42,817
1.3	Switchable Element Development	$397,444	$0
1.4	Electronic Controls Development	$113,055	$0
2	Computational Tool Development	$604,994	$80,405
2.1	Identification of Desired Equiv. Media Prop.	$78,686	$48,648
2.2	Fast Solver Development	$41,650	$23,613
2.3	Realizability of the Desired Effective Medium	$131,605	$0
2.4	Spectral Domain Code Development	$252,408	$0
2.5	ASU Reports and Meetings	$57,311	$8,145
2.6	Transition Plan to Commercial Software	$43,334	$0
3	Array Demonstration	$286,774	$0
3.1	Decade (.2-2 GHz) Lab Demo	$286,774	$0
4	Meetings and Reports	$226,953	$87,982
4.1	TIMs	$93,243	$62,502
4.2	Monthly Status Reports	$37,755	$24,993
4.3	Annual Technical Reports	$95,955	$0

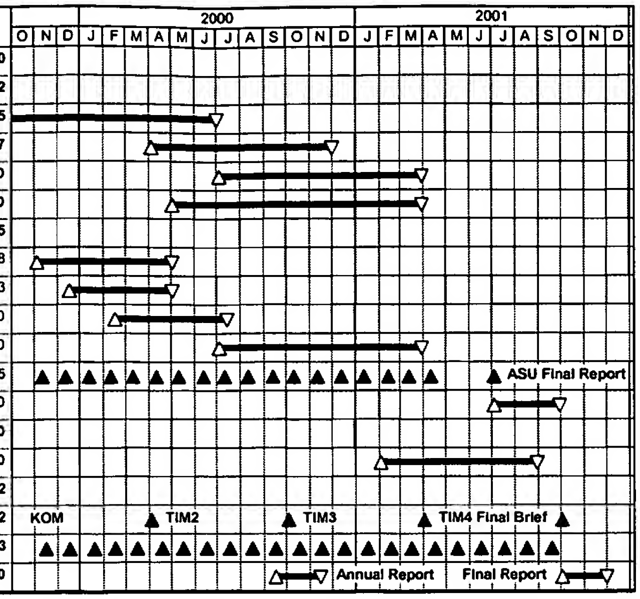


Figure 2a. ARCHES program schedule, budgeted costs, and spending through June 2000.

WBS	Task Name	Budget	Spent
0	ARCHES	$2,500,564	$535,689
1	Integrated Ground PlaneTechnical Dev.	$1,381,843	$354,965
1.1	Passive Broadband AMC Dev.	$325,981	$284,700
1.2	Reconfigurable Bandgap AMC Dev.	$545,363	$70,265
1.3	Switchable Element Development	$397,444	$0
1.4	Electronic Controls Development	$113,055	$0
2	Computational Tool Development	$604,994	$80,405
2.1	Identification of Desired Equiv. Media Prop.	$78,686	$48,648
2.2	Fast Solver Development	$41,650	$23,613
2.3	Realizability of the Desired Effective Medium	$131,605	$0
2.4	Spectral Domain Code Development	$252,408	$0
2.5	ASU Reports and Meetings	$57,311	$8,145
2.6	Transition Plan to Commercial Software	$43,334	$0
3	Array Demonstration	$286,774	$0
3.1	Decade (.2-2 GHz) Lab Demo	$286,774	$0
4	Meetings and Reports	$226,953	$100,318
4.1	TIMs	$93,243	$74,494
4.2	Monthly Status Reports	$37,755	$25,338
4.3	Annual Technical Reports	$95,955	$0

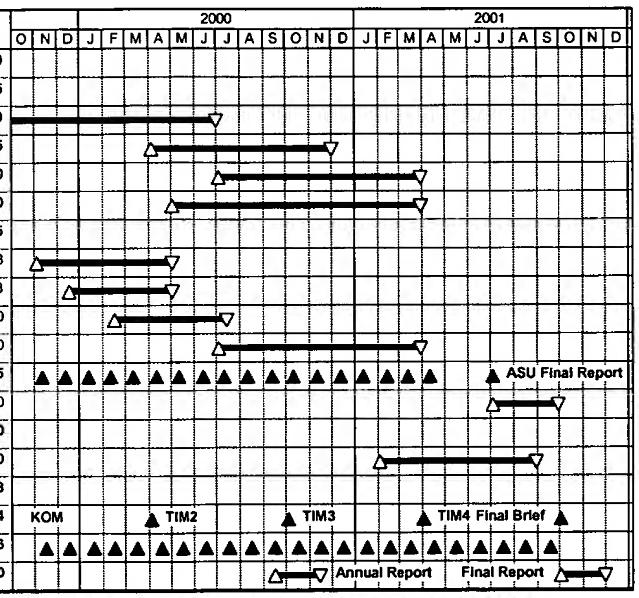
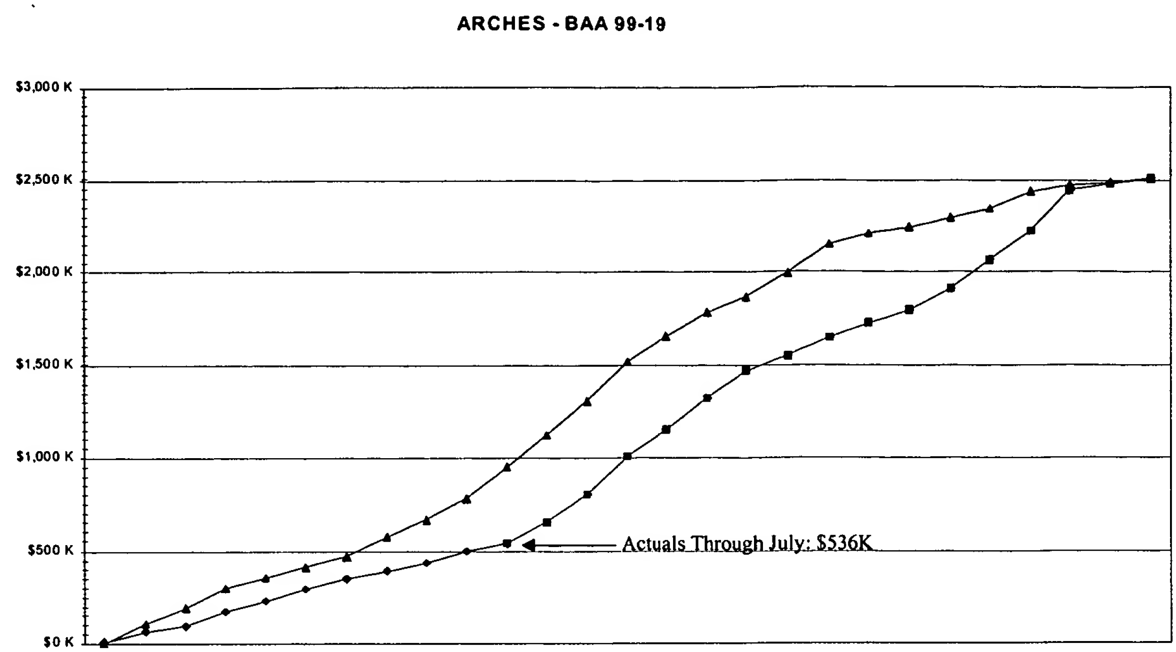


Figure 2b. ARCHES program schedule, budgeted costs, and spending through July 2000.

A breakdown of planned budget for each task is given in Figure 2 for each line item. The second column on this chart shows the cumulative amount spent per line item. The chart shows that as of the end of July, we are approximately 87% spent on task 1.1, 13% spent on task 1.2, 62% spent on task 2.1 and 56% spent on task 2.2 (spending on other technical tasks is zero).

The burn curve through July is shown below in Figure 3. It shows we are underspending the plan. Both Atlantic Aerospace and ASU continue to spend below the original projected levels.



	S-99	O-99	N-99	D-99	J-00	F-00	M-00	A-00	M-00	J-00	J-00	A-00	S-00	O-00
Act thru Jul 00	$5	$62	$92	$170	$229	$289	$345	$387	$429	$494	$536	$653	$801	$1,010
Budget thru Fee	$0	$109	$193	$301	$354	$410	$466	$571	$667	$782	$951	$1,122	$1,306	$1,519
LRE thru completion											$536	$653	$801	$1,010

	N-00	D-00	J-01	F-01	M-01	A-01	M-01	J-01	J-01	A-01	S-01	O-01	N-01
Act thru Jul 00	$1,149	$1,319	$1,467	$1,547	$1,644	$1,722	$1,796	$1,908	$2,064	$2,218	$2,442	$2,472	$2,500
Budget thru Fee	$1,650	$1,783	$1,867	$1,992	$2,149	$2,208	$2,244	$2,290	$2,339	$2,431	$2,466	$2,483	$2,501
LRE thru completion	$1,149	$1,319	$1,467	$1,547	$1,644	$1,722	$1,796	$1,908	$2,064	$2,218	$2,442	$2,472	$2,500

Act thru Jul 00 — Budget thru Fee — LRE thru completion

Figure 3. July 2000 Burn curves: actuals (blue) and budget (red) and LRE through completion (magenta).

4.0 Technical Progress

Task 1.1 Passive Broadband AMC Development: The goal of this task is to design and demonstrate a passive AMC whose surface wave bandgap and impedance bandwidth is an octave in bandwidth for a structure whose electrical thickness is $\lambda_o/50$ at its resonant frequency ($f_o = c/\lambda_o$). In order to achieve this performance, we have determined that materials with permeabilities (μ') of about 5 and permittivities (ε') around 10 with low loss up to 2 GHz are necessary. Note: the derivation of these requirements is contained in the six-month technical interchange meeting, TIM-2, delivered April 10th, 2000.

As reported in TIM-2 and in the previous monthly status report, we have implemented a multi-threaded approach towards achieving these material requirements. The status of our various approaches is summarized below:

- **Unaligned Barium-Cobalt Hexaferrite Tile approach:**

Barium-Cobalt Hexaferrite - $Ba_3Co_2Fe_{24}O_{41}$ (also known in short hand as Co_2Z) has been demonstrated previously (Smit and Wijn, Ferrites, 1959, John Wiley & Sons). This approach is therefore deemed relatively low risk and is our baseline approach.

Tom Countis of Countis Labs has manufactured and tested several samples of this material. During the process, he has discovered that repeating the results of Smit & Wijn is non-trivial. In addition to knowing the ingredients (*i.e.* $Ba_3Co_2Fe_{24}O_{41}$) the exact process of calcining, dry compaction and sintering is critical to obtaining high densities and the proper solid state reaction (*i.e.* crystal lattice). This process, which involves up to 2000 psi and a temperature profile reaching 1300° C over the course of one week, was not recorded in detail by previous authors.

The best samples obtained during this period resulted in $\mu_r'=4$, $\mu_r''= 2$, $\varepsilon_r'=12$, $\varepsilon_r''=2.25$ at 1 GHz (shown in the figure below). The values for the real parts of permittivity and permeability are marginally acceptable for our application. However, the losses are unacceptably high.

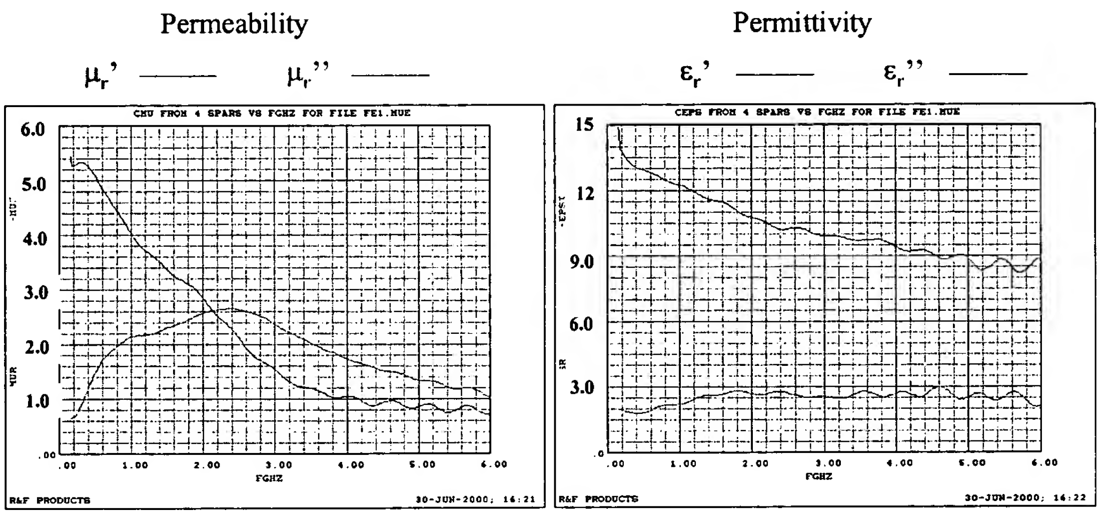


Figure 4. Permeability and Permittivity of Countis Labs Solid Ferrite Sample

- **Barium-Cobalt Hexaferrite Powder in Elastomeric Binder approach:**

This approach is a risk/cost reduction alternative to the solid Co_2Z tiles. During the reporting period, Rick Johnson of R&F Products, received the Praxair Co_2Z powder and began experimenting with various binder materials and mixture packing densities. The goal was to obtain the maximum packing density with a uniform distribution of the ferrite powder. R&F products has achieved 75% to 85% (by weight) packing densities. Even so, the resulting material parameters: $\mu_r'=1.9$, $\mu_r''= 0.2$, $\varepsilon_r'=5.6$, $\varepsilon_r''=0.2$ at 1 GHz have unacceptably low real parts. The material parameter characteristics with frequency are shown in Figure 5 below. Note that this material may be useful, but will not allow us to achieve the desired program goals.

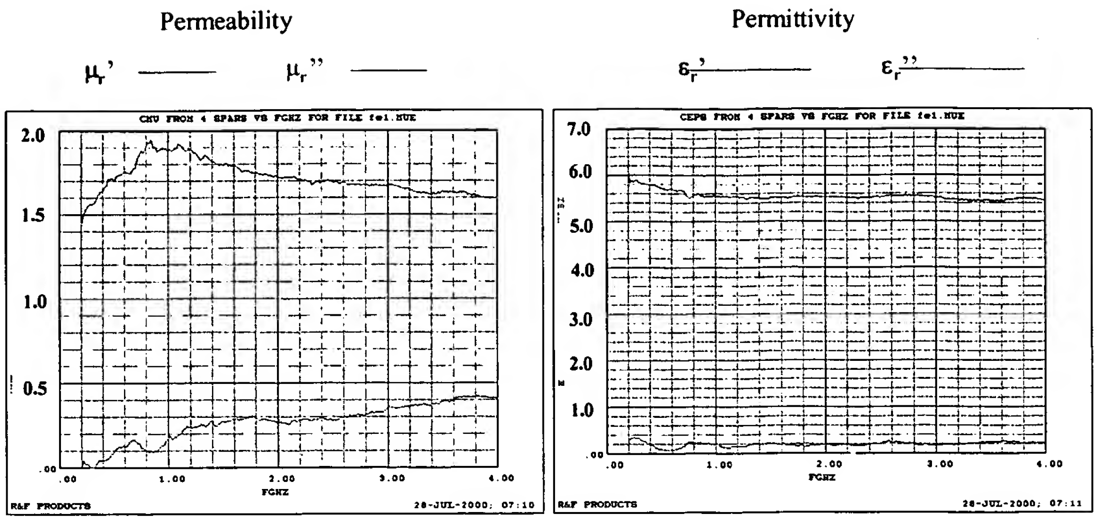


Figure 5. Permeability and Permittivity of Praxair Ferrite Powder Loaded 85% by Weight in Elastomeric Isoprene Binder

Arun Ranade of Particle Technologies is a second vendor producing this powder. During the reporting period, Particle Technologies had troubles with it's fabrication equipment and was therefore not able to produce a sufficient quantity of powder for testing at R&F products. This problem was rectified near the end of the reporting period, and the vendor anticipates delivery of a significant fraction of the 0.5 kg order within the next reporting period. We will promptly deliver this material to R&F products for testing upon receipt.

- **Nickel-Iron Permalloy Nanoflakes in Elastomeric Binder approach:**

This approach represents another alternative to the solid Co_2Z tiles. The approach is to use conventional 80/20 Nickel/Iron permalloy nanoflakes in a lightweight binder that is partially filled with microballoons to occupy volume.

During the reporting period, Rick Johnson of R&F Products procured the nanoflake material from Novamet. The particles were examined under SEM and found to be approximately 45 x 45 x 1 micron (a thinner flake is desired). Here, again, the goal was to obtain the maximum packing density with a uniform distribution of the permalloy flakes. This time, however, the process was severely limited by the physical constraint that the isoprene or silicon binder material tended to "clump up" as the loading percentage increased. The result was that for high percentage loadings, the material became extremely lossy (assumption was that percolation had occurred). A 26% by weight loading was approximately the highest packing density attainable which resulted in low loss. This material yielded the material parameters shown in the figure below. At 1 GHz, the parameters are: μ_r'=1.8, μ_r''= 0.4 , ε_r'=13.5, ε_r''=0.5.

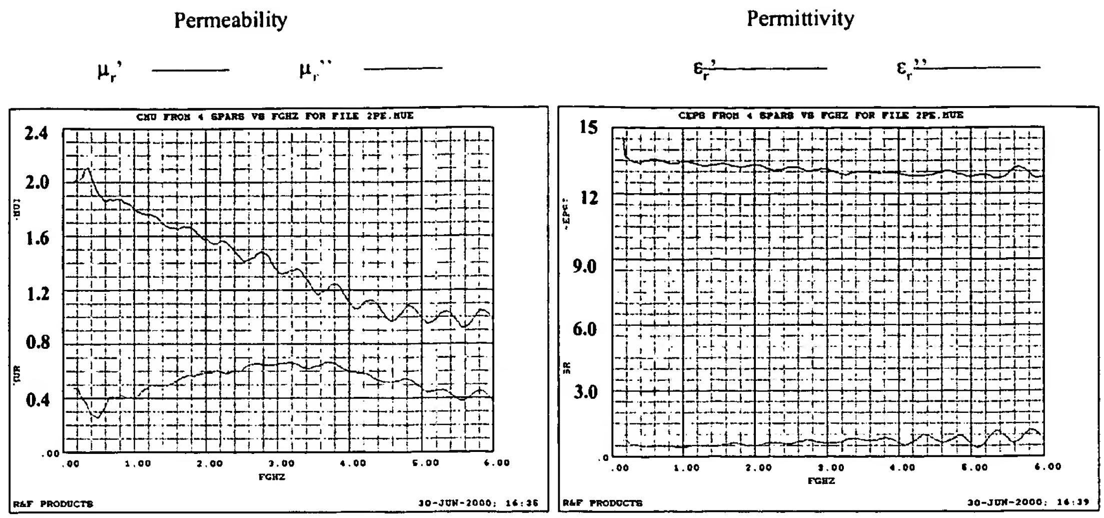


Figure 6. Permeability and Permittivity of permalloy nanoflakes Loaded 26% by Weight in Elastomeric Silicone Binder

- HQ-Iron Powder in Elastomeric Binder approach:

This approach represents yet another alternative to the solid Co_2Z tiles. The approach is to use high-quality iron powder particles in a binder material. The HQ particles are similar to the conventional iron powder spheres typically used in the formation of MAGRAM except they are smaller. These smaller particles result in less eddy-current loss. Again, there is a tradeoff in the material parameters versus loading density (increasing density yields better permeability until a certain point, where percolation occurs and losses increase significantly). A good trade-off point was 40% loading by weight which lead to the following material parameter results at 1 GHz: μ_r'=4, μ_r''= 0.5 , ε_r'=10, ε_r''=0.4. The frequency response of this material is shown in figure 7 below.

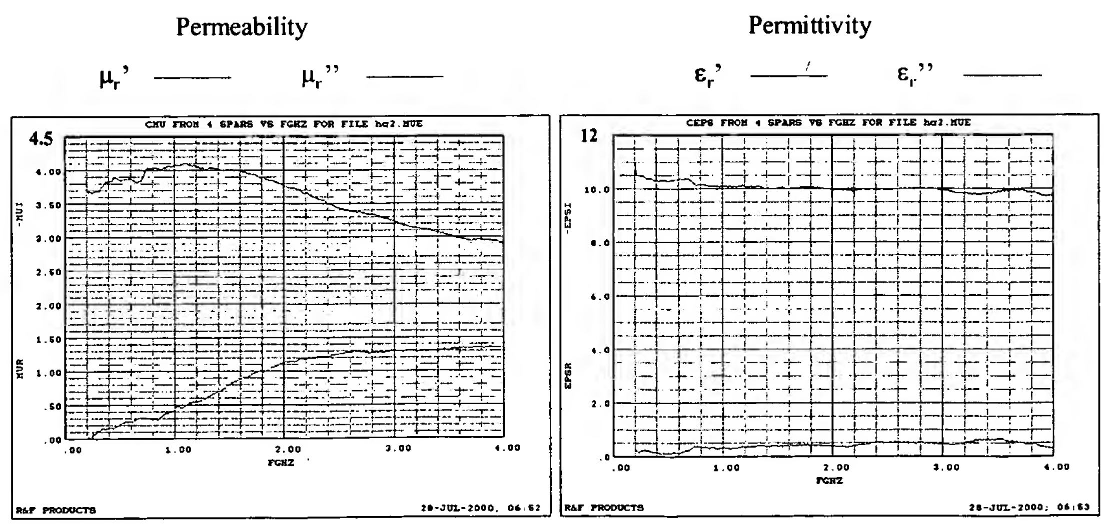


Figure 7. Permeability and Permittivity of HQ Iron Powder loaded 40% by Weight in Elastomeric Silicone Binder

The realization of a broadband, passive AMC structure requires low-loss magnetic materials. A significant amount of effort was expended this reporting period on developing these materials. Iron Powder in elastomeric binder seems to be the most promising candidate material at this point. All other attempts at materials have too low a permeability and/or is too lossy to be useable. The Co_2Z powder from Countis Labs and Praxair as well as the permalloy flakes appear to have a lower permeability than has been reported in the literature.

We have a "fundamental properties" problem that needs to be addressed before structures employing these materials can be used as part of an AMC structure. We anticipate continuing our development of these materials as well as working to analyze and understand the effects of these empirically determined magnetic losses on the surface wave cutoff and reflection properties of AMCs.

Task 1.2 Reconfigurable Bandgap AMC Development: The purpose of this task is to analyze a reconfigurable AMC structure. The initial tuning mechanism to be investigated consists of varactor diodes placed across the capacitive FSS layer patches to obtain variable capacitance, hence a variable tuning state for the AMC. This is shown in figure 8 below. Note that only every 3rd patch will contain a varactor in the initial design to be realized (this is in order to reduce the complexity and cost of the design).

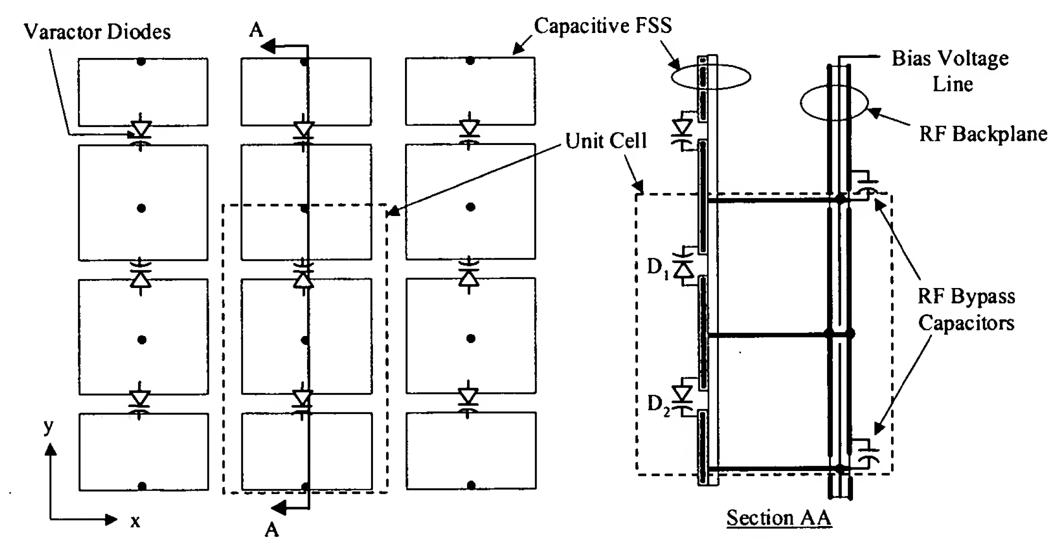


Figure 8. Concept Drawing of AMC Structure with Single-FSS-Layer Varactor-Tuning

Initial modeling was performed using a simple MathCad design tool. This model uses a lumped-element equivalent circuit model for the AMC structure and has previously provided good agreement with both more-detailed models and measurements. Following initial design runs, a more-detailed model (Flomerics' Microstripes Software) was used to refine the design.

The design specifics and predicted reflection-phase performance of the AMC structure is shown in the figures below. The two reflection phase curves are for the extreme cases of the varactor diode bias state. Since the varactor capacitance tunes smoothly with bias voltage, the curve will tune in an analog fashion as bias voltage is applied between these two extreme states. The fabrication and test of this structure is ongoing and will be reported upon in subsequent briefings/reports.

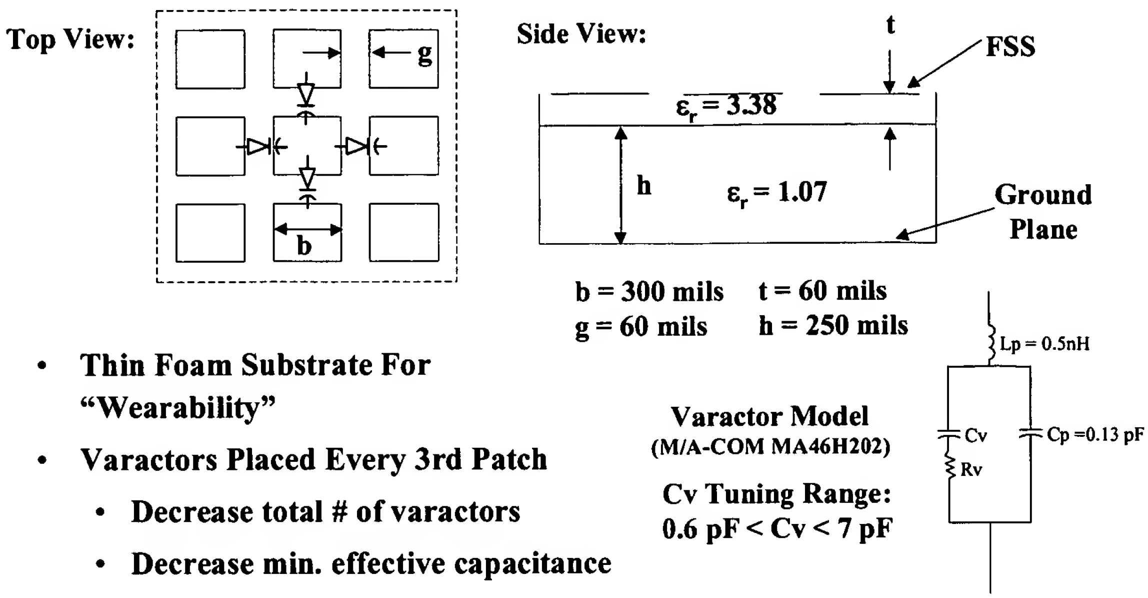


Figure 9. Reconfigurable AMC (RAMC 7) design specifics

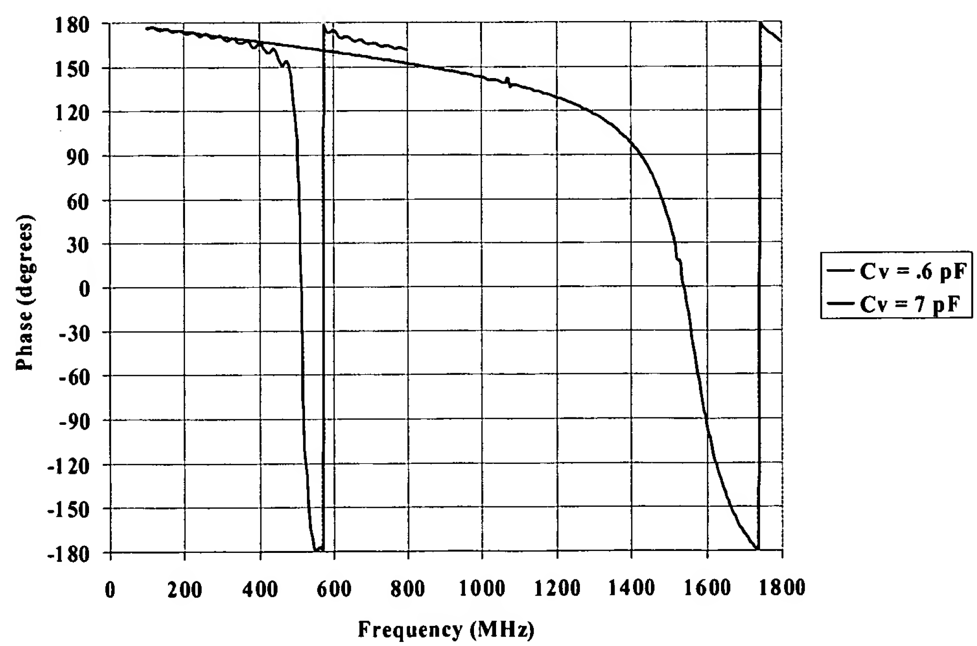


Figure 9. Predicted Reflection Phase for Reconfigurable AMC for extreme cases of bias state

Task 2.1 Identification of Desired Equivalent Media Properties: The purpose of this task is to determine analytically the optimum permittivity and permeability tensors for a two layer conductor-backed substrate, which yields broadband AMC performance. The scope of this task has expanded to include transverse resonance modeling to predict surface wave bandedges, and to include an investigation of commercially available magnetic materials to support a Task 1.1 demonstration of a broadband AMC. A bulletized summary of the technical progress achieved this month is presented below.

- The TE surface wave formulation has been redone using kx as the abscissa. It is found that for Sivenpiper-like AMC's the TE cutoff occurs at least at about 0.9 of the minus 90 degree Reflection Coefficient phase frequency, regardless of the bandwidth. It may actually be exactly at the bandedge or slightly higher depending on the exact value of the z-directed effective permeability of the FSS.
- This bandedge is extremely sensitive to the value of this μz.
- Therefore the TE bandedge can be moved by modifying the z-directed permeability of the FSS layer but in the opposite direction than was suggested in the February 2000 report.
- The TE cutoff appears to be a transition from improper slow waves (exponentially growing in the air space above the AMC) to proper slow waves (exponentially decaying).
- No evidence of the existence of fast leaky waves below the TE cutoff can be found despite the results of FEM model solutions given in the Sievenpiper dissertation.
- The Reaction Theorem was used to estimate the antenna patterns of a bent monopole on an AMC for the H-plane.

Task 2.2 Fast Solver Development: The Sievenpiper AMC is a structured magneto-dielectric, <u>not a PBG</u>. Such an AMC operates below resonance, where the structure's granularity is small compared to the wavelength. It derives its bandgap properties from artificial magneto-dielectric behavior. Therefore to design new AMCs in this family, we are interested in the low frequency properties of structured magneto-dielectrics since these yield their effective medium properties. This is a Laplace equation problem.

An FDTD approach with acceleration has been implemented to solve this set of Laplace equations. During this reporting period, this approach was completed and tested against canonical cases to establish its accuracy and range of applicability. The results show excellent agreement. These results will be incorporated, with significant detail, into the RECAP agents meeting briefing scheduled for August 14th.

Task 4 Meetings and Reports:

Very little time was spent on this task during the month of June. However, in July some time was spent in preparation for the August 14th RECAP agents meeting.

5.0 Plans for the Next Month (August 2000)

In the August period, we will again focus on progress related to of artificial magnetic materials with the goal being an octave bandwidth AMC demonstration. Also, some effort will be expended towards design and implementation of the reconfigurable AMC substrate.